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G.S. Pereselenkov

CORPS OF ENGINEERS, U.S. ARMY
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
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The designing of embankments on bogs raises the problem of forecasting the temperature regime at the base and in the body of the embankment. This is especially important for segments of insular and high temperature frozen ground. This report discusses the calculations necessary for establishing temperature conditions in embankments in bogs.

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CALCULATING TEMPERATURE CONDITIONS IN EMBANKMENTS ON BOGS

Moscow TRANSPORTNOTE STROITEL'STVO in Russian Jul 76 pp 44-46

[Article by G. S. Pereselenkov, candidate of technical sciences: "Reliability of Calculations of Temperature Regimes of Embankments on Bogs"]

[Text] The designing of embankments on bogs (conditions such as on the BAM [Baykal-Amur Railroad] raises the problem of forecasting the temperature regime at the base and in the body of the embankment. This is especially important for segments of insular and high-temperature frozen ground.

Existing methods of calculating engineering tasks for such conditions are based on principles of construction a model of the base soils and schematizing actual conditions of the base's interaction with the embankment and the surrounding medium, also boundary conditions: the time of onset of the interaction between the embankment and the base; their initial temperature, the course of variation in the air and soil temperature; and so on.

This approach to calculations in and of itself conceals a certain amount of danger of errors in the results. In addition, all calculations of this type suffer from a lack of precise error criteria, because it is practically impossible to verify them.

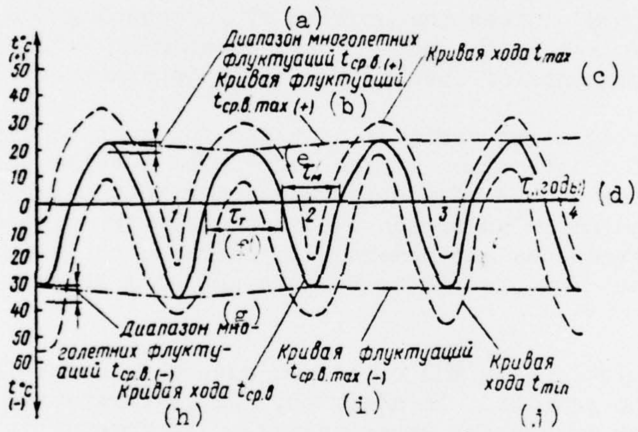
In any attempt to classify the sources of possible errors in these calculations, four main groups emerge. Errors of the model, due to deviations of the actual heat transfer conditions from those assumed in the model, to differences in the assumed and the actual ratio of conductive and convective heat exchange, and to inaccurate model reproduction of the actual properties of the embankment earth and the base.

Errors in initial data, due to discrepancies between the parameters of actually poured soils and those assumed in the design and calculation, and to great variety and spread of parameter values of the soils of the bog itself (See TRANSPORTNOYE STROITEL'STVO No 5, 1970, p 39). Errors in boundary conditions, which must include deviations from calculated values in the actual values of temperatures, the type and conditions of

the soil at the onset of interaction between the embankment and the base and on completion of the pouring of the embankment.

Errors in forecasting the course of variation in temperatures, due to the impossibility of keeping track of daily or even monthly fluctuations in air temperatures in the areas of interest under conditions of extreme variation ranges. This group also includes errors in forecasting soil surface temperatures because of fluctuations at the boundary dividing the air and the soil medium, due to fluctuating amounts of solar radiation, the effect of wind, variations in air humidity, and the effect of precipitation (Fig 1).

This great variety of influencing factors makes it possible to consider calculation results as random values, with a rather large range of possible values; this is generally confirmed in attempts to compare calculated with statistical data of observations and frozen-ground studies in the process of engineering-geological surveys.



Key:

a. Range of many-year fluctuations $t_{av.val.(+)}$

b. Curve of fluctuations $t_{av.val.max(+)}$

c. Curve of path t_{max}

d. τ, (years)

e. τ_f

f. τ_t

g. Range of many-year fluctuations $t_{av.val.max\ (-)}$

h. Curve of path $t_{av.val.}$

i. Curve of fluctuations, $t_{av.val.max\ (-)}$

j. Curve of path t_{min}

The results of thermotechnical calculations are among the basic initial data in the designing of transverse profiles of an earthen bed, and designation of the size of the "safety factor" to prevent deformations or to reduce them to a level permitting satisfactory operation of the roadway does not always achieve the purpose, especially in the projecting of embankments according to Principle II (maintaining the degree of freezing in the base). For this reason, it appears advisable to determine the reliability of these results and then to undertake to stipulate the extent of their reliability by norm. This requires concerted efforts to reduce the effect of possible sources of error in all the four main groups mentioned above, or to compensate for them.

Of considerable interest are calculations of reliability in determining the depth of season thawing and forecasting the level of stabilization in the upper boundary of frost (VGM).

As is well known, the depth of seasonal thawing is determined by examining conditions of heat exchange in soils by solving the task of three-dimensional thermal process. For practical engineering calculations, the three-dimensional task can be reduced to a two-dimensional or one-dimensional scheme and solved with varying degrees of refinement, for which many years of research in this field have developed calculation formulas. Recently, algorithms and programs have been developed for making the necessary calculations by means of computers.

Many years of experience have established the sphere of rational application of each of these calculations methods. Further searches for new calculation formulas constitute a separate problem.

For this reason, to illustrate the calculation of reliability in determining the depth of season thawing (freezing) $H_{t(f)}$, we can make use of Stefan's formula, the simplest and therefore the most widely used [1]:

$$H_{t(f)} = \frac{\sqrt{2\lambda_{t(m)} t_{av.val.} \tau_{t(f)}}}{Q_{l.h.}} \qquad (1)$$

where $\lambda_{t(f)}$ is the coefficient of heat conductivity of thawed (during thawing) of frozen (during freezing) soil;

$t_{av.val.}$ is the average temperature of the soil surface (air) during the thawing (freezing) period;

$\tau_{t(f)}$ is the duration of the thawing (freezing) period;

$Q_{l.h.}$ is the amount of latent heat in the soil, absorbed by the ice during thawing or given off by water during freezing.

$$Q_{l.h.} = 0.8_{\gamma sk} W_{grav} I; \qquad (2)$$

where γ_{sk} is the volume weight of the soil skeleton;

W_{grav} is the gravimetric moisture content of the soil;

I is the iciness of the soil.

The volume weight of the soil skeleton, its gravimetric moisture content, iciness, and the closely-associated coefficient of heat conductivity can have various values not only within one bog but also in adjacent cross sections. Average soil surface temperatures and the duration of the thawing and freezing period can also vary in different years. All this makes it possible to view the depth of thawing (freezing) as a system of random values:

$$H_{t(f)} = \Lambda\, TD \qquad (3)$$

where is the random values of soil characteristics;

$$\Lambda = \frac{\sqrt{2\lambda_{t(f)}}}{Q_{l.h.}} = \sqrt{2.5\lambda_{t(f)}\gamma_{sk}^{-1}W_{grav}^{-1}I^{-1}} \quad ; \qquad (4)$$

t is the random value of average soil surface (air) temperature over the thawing (freezing) period:

$$T = \sqrt{t_{av.val.}}\,; \qquad (5)$$

D is the random value of the duration of the thawing (freezing) period:

$$D = \sqrt{\tau_{t(f)}}\ . \qquad (6)$$

The spread of values for each of these random values, as a rule, can be assessed from field date of engineering-geological surveys, observations of meteorological stations, and frozen-ground studies along the route.

Taking the distribution of the probably values of these random values to be subject to the normal law, which can be assumed, and proceeding on Lyapunov's theorem, since the values of each of them depend on a large number of influencing factors, it is possible to utilize Chebyshev's inequality (the "three sigma" rule) and find the standard deviation for each.

Accordingly, it is possible to determine the standard deviations of the thawing (freezing) depths as functions of the random value of arguments making up the system [2].

This distribution of this function should also be subject to the normal law and can be written as:

$$f(H_\lambda;\ H_t;\ H_D) = \frac{1}{\sigma_{H\lambda}\sigma_{H_t}\sigma_{H^D}\sqrt{2^3\pi^3}} \times \frac{-(H_{\Lambda_i}-mH_\Lambda)^2}{2\sigma^2 H_\Lambda} -$$

$$-\frac{(H_{t_i} - mH_t)^2}{2\sigma^2 H_t} - \frac{(H_{D_i} - mH_D)^2}{2\sigma^2 H_D}, \qquad (7)$$

where H_Λ; H_t; H_D represent the depths of thawing (freezing) as functions of random arguments of soil parameters and thawing (freezing) periods, respectively;

mH_Λ; mH_t; mH_D represent mathematical expectations of corresponding functions of random arguments;

$\sigma_{H\Lambda}$; σ_{Ht}; σ_{HD} represent standard deviations of corresponding functions.

If we now take 10 percent to the maximum deviations between actual thawing (freezing) depths and calculated ones, the reliability of calculation of the thawing (freezing) depth will be expressed by the probability

$$P\left(0.9H_{av.cal} \leq H_{act} < 1.1H_{av.cal}\right) = \int_0^{1.1}\int_{.9}^{1.1}\int_{0.9}^{1.1}\int_{0.9}^{1.1} f(H_\Lambda;\ H_T;\ H_D)\, dH_\Lambda dH_T dH_D = \frac{1}{2^3}\left[\hat{\Phi}\left(\frac{1.1-1.0}{\rho\sigma_{H\Lambda}\sqrt{2}}\right) - \right.$$

$$\left. - \hat{\Phi}\left(\frac{0.9-1.0}{\rho\sigma_{H\Lambda}\sqrt{2}}\right)\right]\left[\hat{\Phi}\left(\frac{1.1-1.0}{\rho\sigma_{H_T}\sqrt{2}}\right) - \hat{\Phi}\left(\frac{0.9-1.0}{\rho\sigma_{H_T}\sqrt{2}}\right)\right] \times \qquad (8)$$

$$\times\left[\hat{\Phi}\left(\frac{1.1-1.0}{\rho\sigma_{HD}\sqrt{2}}\right) - \hat{\Phi}\left(\frac{0.9-1.0}{\rho\sigma_{HD}\sqrt{2}}\right)\right].$$

where Φ is the normalized Laplace function;

$H_{av.val.}$ is the average calculated depth of thawing, computed for the average values of Λ, T, and D.

For example, for sandy loam soil with the following initial data: $t_{av.val.}$ = (11°—10°)C; τ_t = (200--190) days; Λ_t = (1.14--1.10) kcal/m·hr·deg; λ_{sk} = (1.6—1.2) g/cm^3; W_{grav} = (40--30) %; I = (0.8--0.6); $H_{av.cal.}$ = 2.01 m,

H_{max} = 2.43 m, H_{min} = 1.72 (Fig. 2), the reliability of determining the thawing depth came to 0.3.

Increasing the degree of reliability of calculation requires, above all, more accurate meteorological data. In particular, if the period of positive temperatures in this calculation were specified within 197--193 days, the reliability of calculation would be increased to 0.7.

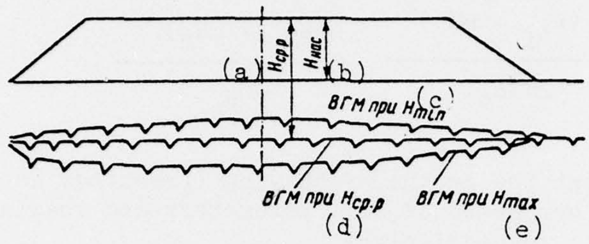


Fig. 2

Key:

a. $H_{av.cal.}$

b. H_{act}

c. VGM at H_{min}

d. VGM at $H_{av.cal.}$

e. VGM at H_{max}

Reliability in predicting the level of stabilization of the upper boundary of frozen group can be determined by representing the embankment and the thickness of the active layer under it as a technical system whose mode of operation --thawing or freezing--varies randomly. "Breakdown" of the system can begin in each mode if its duration is greater than is necessary for full thawing or freezing.

The states of the system (Fig 3) will be:

1) warming mode; the system is "operating" as thawing proceeds;

2) warming mode; the system "breaks down" as VGM declines;

3) cooling mode; the system is "operating" as freezing proceeds;

4) cooling mode; the system "breaks down" as cold accumulates.

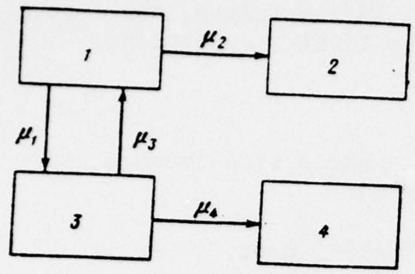


Fig. 3

The intensity of the flow of events μ_1 under which the system converts from the thawing to the freezing mode is proportional to the ratio of the heat released into the atmosphere to the amount of heat entering the soil. The reverse transition takes place under the effect of the flow of events μ_3, proportional to the inverse ratio. "Breakdown" of the system in the thawing mode takes place under the effect of the "flow of breakdowns" μ_2, proportional to the ratio of the difference of the maximum and the average calculated amount of heat entering the soil to the average calculated amount of heat entering the soil. "Breakdown" of the system in the freezing mode μ_4 takes place with respect to the analogous ratio of the amount of heat escaping into the atmosphere:

$$\mu_1 = \frac{t_{av}T(-)}{t_{av}T(+)}; \qquad \mu_2 = \frac{t_{av_{max}}T_{max}(+) - t_{av}T(+)}{t_{av}T(+)}; \tag{9}$$

$$\mu_3 = \frac{t_{av}T(+)}{t_{av}T(-)}; \qquad \mu_4 = \frac{t_{avmax}T_{max}(-) - t_{av}T(-)}{t_{av}T(-)},$$

For the probability of the operating states of the system we can write Kolmogorov's equation [3]:

$$\frac{dp_1}{dt} = -(\mu_1 + \mu_2)p_1 + \mu_3 p_2 \tag{10}$$

$$\frac{dp_2}{dt} = -(\mu_3 + \mu_4)p_2 + \mu_1 p_1,$$

where p_1 and p_2 are probabilities of states 1 and 3 respectively.

The initial conditions in which these equations are integrated are determined by the initial operating mode of the system.

For example, if the embankment has been poured in the summer, the system begins to operate in the thawing mode with these initial conditions:

$$t = 0;\ p_1 = 1;\ p_2 = 0.$$

Filling out the initial data of the preceding example with average air temperatures and the duration of the frost period:

$$t_{av.val.} = -(18°\div16°)C;\ t_f = (175\div165)\ \text{days},$$

which makes it possible to assume:

$$\mu_1 = 1.4;\ \mu_2 = 0.8;\ \mu_3 = 0.71;\ \mu_4 = 0.09;$$

and, as a result of calculations, to transform the equations of (10) into the form:

$$\frac{dp_1}{dt} = -1.48p_1 + 0.71p_2;$$

$$\frac{dp_2}{dt} = -0.8p_2 + 1.4p_1,$$

integrating for the initial mode

$$t=o;\ p_1=1;\ p_2=0;$$

we get

$$p_1(t)=0.337\ e^{-0.09t} + 0.663\ e^{-2.19t};$$

$$p_2(t)=0.663(e^{-0.009t} - e^{-2.19t}).$$

Accordingly, for the initial mode

$$t=0;\ p_1=0;\ p_2=1;$$

(i.e., for winter pouring of the embankment), we get

$$p_1(t) = 0.337(e^{-0.09t} - e^{-2.19t});$$

$$p_2(t) = 0.663(e^{-0.09t} + 0.337e^{-2.19t}).$$

The reliability of the system in both cases will be:

$$p(t) = p_1(t)+p_2(t)=e^{-0.09t}.$$

As can be seen, this reliability is not very high--in just five or six years the maintenance and breakdown of the VGM level will become equally probable.

However, an examination of the reliabilities of the "operating state" of the system in the thawing mode $p_1(t)$ and in the freezing mode $p_2(t)$ shows that during freezing the system "operates" approximately twice as reliably. This makes it possible to assume that in this case there will be no decline in VGM.

At the same time, putting the system "into operation" during the winter somewhat increases its reliability in the freezing mode (by $e^{-2.19t}$)--that is, the probability of degradation of the frozen ground declines. Further refinement in reliability calculations will make it possible to assess the design of embankments in bogs in more detail and to predict their interaction with the base in time.

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